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FORESTER'S GUIDE TO

AERIAL PHOTO INTERPRETATION

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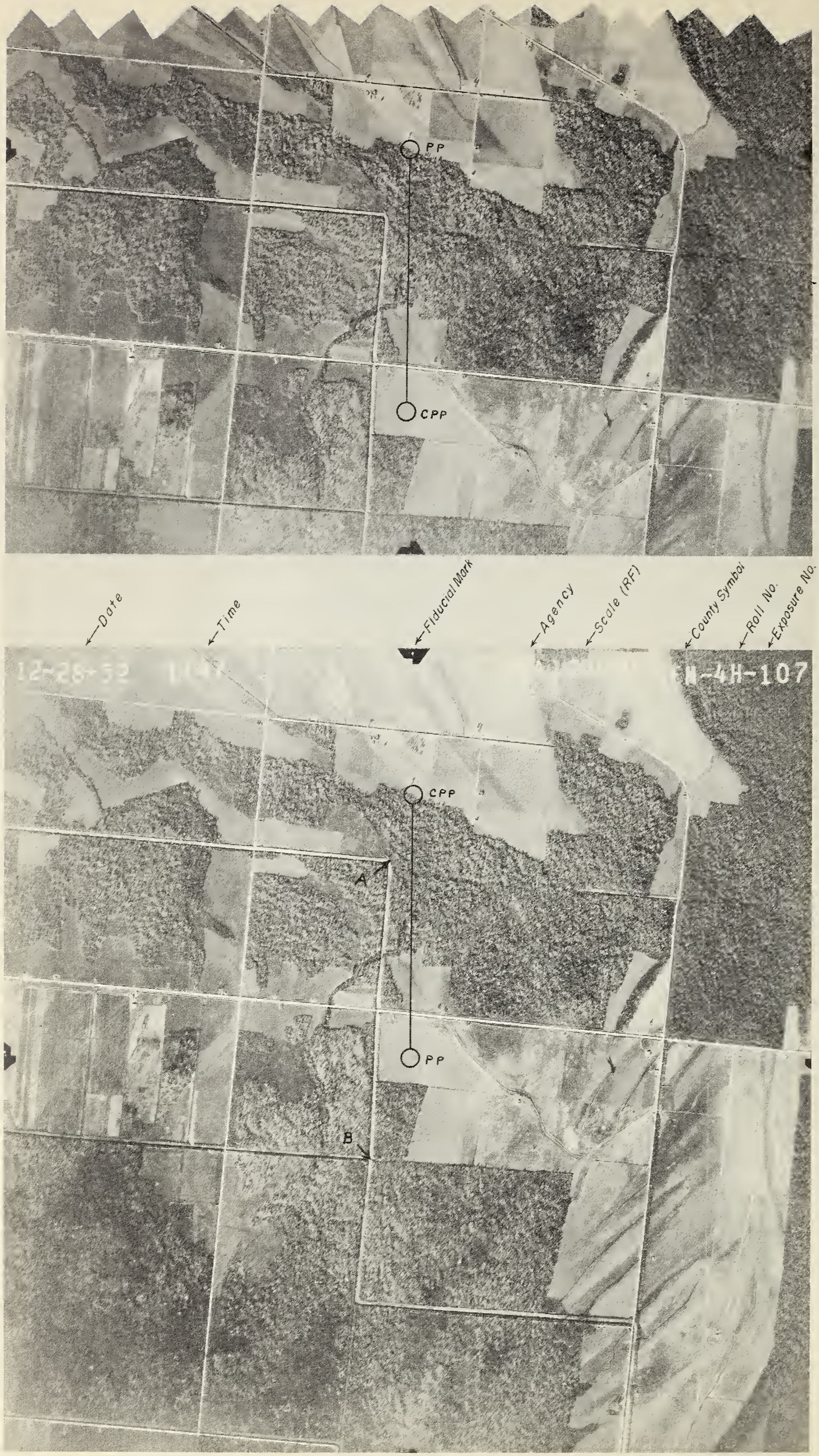

PP
CPP
Date
Time
Fiducial Mark
Agency
Scale (RF)
County Symbol
Roll No.
Exposure No.
12-28-52
M-4H-107
CPP
A
PP
B

FORESTER'S GUIDE TO AERIAL PHOTO INTERPRETATION

Gene Avery
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This guide is intended as a practical reference on techniques of aerial photo interpretation in forest inventory. It is written for the forester with a casual knowledge of aerial photography. No attempt is made to cover complex subjects like topographic mapping or operation of expensive stereo-plotting instruments. Although single prints are occasionally useful, emphasis is on stereoscopic interpretation of vertical aerial photographs available from various agencies of the U. S. Department of Agriculture (USDA). Southern forest conditions are stressed, but the basic techniques are applicable in most of the United States.

With a minimum of training, the forester can use photos to determine bearings and distances, identify broad forest types, and measure areas. Additional experience will enable him to improve the efficiency of timber cruising by distributing field samples on the basis of photo classifications. In some instances, he may even be able to estimate timber volumes directly from the photographs.

While photo interpretation may make the forester's job easier, it has limitations. Accurate measurements of such items as tree diameter, form class, and stem defect are possible only on the ground. Aerial photographs are best employed to complement, improve, or reduce field work rather than take its place.

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Figure 1.--Nomenclature of an aerial stereo-pair, reduced from 9- by 9-inch contact prints. The lower photo is the southernmost print in the flight line, as evidenced by the time of day shown. Note that the principal point (PP) of one photo coincides with the conjugate principal point (CPP) of the other. The flight line connects these points on each print.

The section line AB near the center furnishes a check of photo scale. Assuming the ground distance to be one mile and the photo measure on the contact print 3.28 inches (0.273 foot), the RF (natural scale) would be $\frac{0.273}{5280.0} = \frac{1}{19,340}$.

OBTAINING AERIAL PHOTOGRAPHY

Users of this guide will ordinarily rely on prints of existent photography flown for other agencies. Thus there is no need here to discuss specifications for new aerial photography. Details of flight planning and photographic contracts are adequately covered in the Manual of Photogrammetry (1). [1]

Sources of aerial photography.--Almost all of the United States has been photographed one or more times in recent years for various agencies of the U. S. Government. The basic key to such photography is available free in map form as the "Status of Aerial Photography in the U. S." Current copies may be obtained by writing to:

Map Information Office
U. S. Department of the Interior
Geological Survey
Washington 25, D. C.

This map depicts all areas of the U. S., by counties, which have been photographed by or for the following agencies: Commodity Stabilization Service, Soil Conservation Service, Forest Service, Geological Survey, Corps of Engineers, Air Force, Coast and Geodetic Survey, and commercial agencies. Names and addresses of agencies holding the negatives for such photography are printed on the back of the map, so that inquiries can be sent directly to the appropriate agency. There is no central laboratory that can furnish prints of all government photography.

The agency holding the largest share of recent aerial photography is the Commodity Stabilization Service (CSS) of the Department of Agriculture. This is the same agency formerly known as the Agricultural Adjustment Administration (AAA) and the Production and Marketing Administration (PMA). Techniques in this guide are directed primarily toward this inexpensive, available photography.

Large forest industries often have private aerial surveys made of their lands, and small ownerships adjacent to or within such areas may be included. Thus by checking with local lumber and pulp and paper companies, the forester may find that ideal photography of bordering areas is available. The aerial mapping company usually retains the negatives and must have the written permission of the original purchaser before it can sell prints.

Films, season, and date of photography.--Two types of black-and-white aerial film are in common use: panchromatic and infrared. Panchromatic photography offers better resolution and lighter shadows, but exhibits little

1/ Underscored numbers in parentheses refer to Literature Cited, p. 40.

tonal contrast among different forest types. Modified infrared[2] photography presents a maximum of contrast between pines and hardwoods, but wet sites and shadows register in black, thus restricting interpretation. Where a choice is available, most foresters select infrared photography because of easier forest type separations (fig. 2).

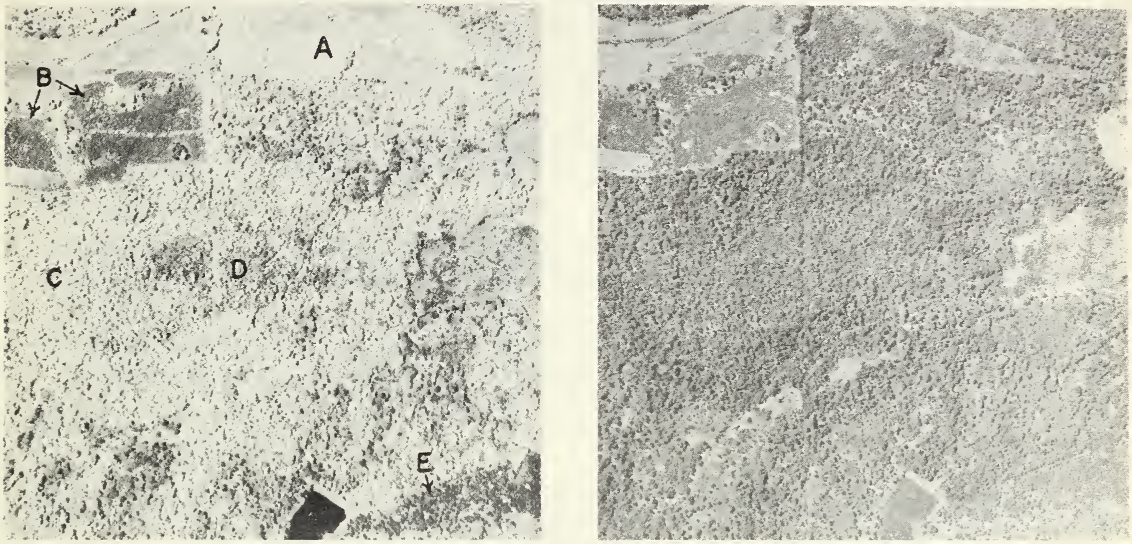


Figure 2.--Modified infrared (left) and panchromatic photography of the same area. Easily distinguished in the left photo are hardwood saplings (A), pine saplings (B), hardwood sawtimber (C), pine-hardwood poles (D), and pine sawtimber (E). Scale: approximately four inches per mile. Photographs courtesy of The Crossett Company.

Either kind of photography is preferably taken during the growing season, so that reliable photo measurements are possible for deciduous species. Infrared usually meets this requirement, as it is likely to be flown specifically for forestry purposes. Most available panchromatic photography in the South has been taken in winter. Pines can be distinguished from hardwoods on these photos, but interpretation of hardwood stand-sizes is difficult (fig. 8, p. 12). Modified infrared photography is occasionally available for tracts near large forest ownerships or national forests, but most interpreters are limited to the common USDA panchromatic photography.

If there is a choice between photography of different dates, it is best to give prime consideration to the most recent. In the South, rapid growth and frequent cutting make photos more than five years old of questionable value for interpretation.

2/ Modified infrared photography employs a filter, usually of a minus-blue type, to reduce extreme contrast and improve image resolution.

Photo scales and enlargements.--Available aerial photographs range in nominal scale from about 1:12,000 to 1:20,000. Contact prints are standardized at the 9- by 9-inch size. Forest industries often contract for photography at 1:15,840 (four inches per mile), but few extensive areas in the eastern U. S. have been photographed at scales as large as 1:12,000.

USDA photography is normally at 1:20,000 (3.17 inches per mile). This is the smallest scale that can be used efficiently by non-professional interpreters with a minimum of equipment. Although enlargements of USDA photography can be obtained, they cost more, yield no additional detail, and cannot be viewed with simple stereoscopes. Contact prints are recommended for general use, unless enlargements present definite advantages in transfer of photo detail to base maps.

Paper surface, weight. and contrast.--Photographic prints from USDA are available with glossy or semi-matte finishes. Glossy prints exhibit an offensive glare and are difficult to write upon; they also develop emulsion cracks with excessive handling and are not suited to necessary bending under the lens stereoscope. Semi-matte prints are more desirable because they have a minimum of glare, a "toothed" surface easily marked on, and fair resolution qualities.

Photographs can be obtained on either single- or double-weight papers. Single-weight papers are suitable for office use, take up less filing space, and are easy to handle under the lens stereoscope. Double-weight papers are preferred for field use, however, as they are less subject to dimensional changes and withstand handling better than single-weight papers. Most USDA photography is furnished on double-weight, semi-matte paper unless otherwise specified. Contact prints may be obtained on special low-shrink, waterproof papers at a slight increase in price.

The contrast of aerial prints should also be specified where a choice is available. Some USDA laboratories offer three degrees of print contrast: "soft" for mapping, "normal" for general use, and "contrast" for timber survey work. The photograph should present maximum tonal differences between timber types without loss of image detail in light and dark areas. Although the contrast is limited primarily by the quality of the original exposure, new electronic printing devices get excellent contrast from all but the poorest negatives.

Ordering Commodity Stabilization Service photography.--Photo index sheets or index mosaics, showing the relative positions of all individual photographs within a given county, usually can be examined at local offices of the Commodity Stabilization Service, Soil Conservation Service, or Agricultural Conservation Program. The number of index sheets per county varies from one to six or more. Foresters working regularly with aerial photographs may find it desirable to purchase a set of index sheets for areas where their work is concentrated.

In deciding which photographs should be ordered, the boundaries of the desired area can be outlined on the photo index. All photographs which overlap this area, partially or completely, should be included to insure stereo-coverage. Prints should be ordered by county symbol, roll number, and exposure number (fig. 1). Other items to specify are:

Photo date--upper left corner of each print.
Scale--such as 1:20,000 or 1,667 feet per inch.
Reproduction--such as 9-by 9-inch contact prints, double-weight, semi-matte paper, with "contrast" finish.

Order forms (CSS-441) are available at most CSS offices. If such an office is not convenient, orders may be placed at the addresses below.

Eastern Laboratory, for photography of Texas, Oklahoma, Nebraska, South Dakota, and all States eastward:

Performance and Aerial Photography Division
Commodity Stabilization Service
U. S. Department of Agriculture
Washington 25, D. C.

Western Laboratory, for photography of Kansas, North Dakota, and all States westward:

Performance and Aerial Photography Division
Commodity Stabilization Service
U. S. Department of Agriculture
167 West Second South
Salt Lake City 1, Utah

Photo index sheets, usually at a scale of one inch per mile, cost $1.10 for a sheet 20 by 24 inches in size.

Contact prints, 9 by 9 inches, 1:20,000, 8-1/4-inch focal length:

Quantity	Price per print
1-100	$0.65
Over 100	.50
Complete county coverage	.45

Enlargements are available at four scales ranging from 1:15,840 on prints 14 by 14 inches to 1:4,800 on prints 40 by 40 inches. Prices run from about $1.70 to $5.10 per print.

These prices are as of September 1957, but are subject to revision at any time. Payment must be made in advance, preferably by money order, and six to eight weeks are usually required for delivery.

PREPARING PHOTOGRAPHS FOR STEREO-VIEWING

EQUIPMENT NEEDED

Equipment considered essential by one interpreter may be of limited use to another, but the forester who anticipates a continued use of aerial photographs will probably find that the following list closely approximates his minimum needs. If purchased with discretion, essential items can be obtained for less than $100.

Lens stereoscope, folding pocket type.
Parallax bar or parallax wedge for measuring object heights.
Engineer's scale, 6 or 12 inches in length, reading to 1/50-inch.
Tree crown-density scale.
Tree crown-diameter scale, either wedge or dot type.
Dot grids for acreage determination (can be improvised).
China-marking pencils for writing on photographs.
Carbon tetrachloride and cotton for removing pencil markings from photographs.
Drafting instruments, triangles, and drafting tape.
Needle prick for point-picking (can be improvised).
Tracing table (can be improvised).
Clip board for holding stereo-pairs for viewing (can be improvised).

A list of inexpensive photo-interpretation equipment and supplies, including manufacturers and prices, has been compiled by the Lakes States Forest Experiment Station (2). A price list of aids available from the U. S. Forest Service may be had on request to the Division of Engineering, Forest Service, U. S. Department of Agriculture, Washington 25, D. C.

Many foresters will already own such items as drafting instruments, dot grids, and pocket stereoscopes. A satisfactory tracing table can be improvised by installing a uniform light source under a glass surface. Fluorescent tubes are preferred because they produce less heat than incandescent bulbs. A sheet of frosted cellulose acetate between two pieces of ordinary single-weight glass serves very well when special frosted glass is not available.

A clip board to eliminate the need for holding stereo-pairs with drafting tape can be improvised with a few ordinary spring clips and a piece of plywood or masonite about 11 by 18 inches. Figures 5 and 6 (p. 8) illustrate two types, one of which enables the viewer to see the "hidden area" of the overlap by turning the edges of the photos downward into a central slot. Another satisfactory design is described by Hawes (3).

As the forester uses aerial photographs with greater regularity and becomes more adept in interpretation and mapping, he may wish to acquire more expensive equipment, such as a mirror stereoscope, vertical sketchmaster, reflecting projector, or radial plotting devices. Such items cost up to several hundred dollars. Because they would likely be of limited value to most users of this guide, they will not be discussed here. Interested persons may obtain information on such equipment in the Manual of Photogrammetry (1).

PREPARING THE PHOTOGRAPHS

Photographic flights are planned so that prints will overlap about 60 percent of their width in the line of flight and about 30 percent between flight strips. For effective stereo-viewing, prints must be trimmed to the nominal 9- by 9-inch size, preserving the four fiducial marks at the midpoint of each of the edges (fig. 1). Then:

(1) Locate the principal point (PP) or center of each photo. Align opposite sets of fiducial marks with a straightedge or triangle. Draw a cross at photo center with a wedge-pointed pencil, and make a fine needle hole at the intersection (fig. 3).

(2) Locate the conjugate principal points (CPP's) on each photograph--the points that correspond to PP's of adjacent photos. Adjust stereoscope until distance between centers of lenses corresponds with interpupillary distance (usually about 2.5 inches). Arrange the first two photographs of a given flight line so that corresponding gross features overlap. Shadows should be toward the observer; if they fall away from the viewer there is a tendency to see relief in reverse. Tape down one photograph. Move adjacent photograph in direction of line of flight until corresponding images on each print are about 2 or 2-1/4 inches apart. Place lens stereoscope over prints parallel to line of flight so that the left-hand lens is over the left photo and the right-hand lens is over the same area on the right photo. The area around the PP will be seen as a three-dimensional image. The movable photo should then be fastened down. While viewing this area through the stereoscope, place a needle in the same area on the adjacent photo until it appears to fall precisely in the hold pricked for the PP. This locates the CPP (fig. 4), though a monocular check should

Figure 3.--Locating the principal point of a photograph with a triangle and wedge-pointed pencil. The intersection of lines from opposite fiducial marks locates the center. Prints shown here have not yet been trimmed.

Figure 4.--Locating the conjugate principal point of a photograph with pocket stereoscope and needle pointer. The principal point of the left photo, marked with an inked circle, is transferred stereoscopically to the identical point on the right photo.

be made before the point is permanently marked. Repeat for all photos; each will then have one PP and two CPP's, except that prints falling at the ends of the flight lines will have only one CPP. Ink a 0.2-inch diameter circle around each PP and CPP (fig. 1).

(3) Locate the flight lines on each print by aligning the PP's and CPP's. Connect the edges of the aligned circles with a finely inked line (fig. 1). Because of lateral shifting of the photographic plane in flight, a straight line will rarely pass through the PP and both CPP's on a given print.

(4) Determine the photo base length for each stereo-overlap by averaging the distance between the PP and CPP on one photo and the corresponding distance on the overlapping photo. Measure to the nearest 1/50-inch and record on the back of each overlap. There will be two average base lengths for each print, i.e., one for each set of overlapping flight lines.

Aligning prints for stereoscopic study.--A print is selected and clipped down with shadows toward the viewer. The adjacent photo is placed with its CPP about 2 to 2-1/4 inches from the corresponding PP on the first photo. With flight lines superimposed, the second photo is positioned and clipped down. The stereoscope is placed with its long axis parallel to the flight line and with the lenses over corresponding photo images. In this way an overlapping strip 2 to 2-1/4 inches wide and 9 inches long can be viewed by moving the stereoscope up and down the overlap area.

With the photos still clipped down, the prints can be flipped into reverse position with the opposite photo on top. This presents another area of the overlap for stereo-viewing. To study the narrow strip between, the edge of one print must be curled upward or downward and the stereoscope moved parallel to the flight line until the "hidden area" comes into view (figs. 5 and 6).

Figure 5.--Curling one photograph upward to expose the 'hidden area' of the stereo-overlap. Prints are held on the board with spring clips.

Figure 6.--Slotted clip board for bending prints downward and out of the way of the viewer. The area indicated by arrows would not be visible under the stereoscope if the prints were overlapped as in figure 4.

The vertical aerial photograph presents a true record of angles, but measures of horizontal distances are subject to wide variation because of changes in ground elevations and flight altitudes. The nominal scale (as 1:20, 000) is representative only of the datum, an imaginary plane passing through a specified ground elevation above sea level. Calculation of the average photo scale will increase the accuracy of subsequent photo measurements.

Aerial cameras in common use have focal lengths of 6, 8-1/4, or 12 inches (0.5, 0.6875, or 1.0 ft.). This information, coupled with the altitude of the aircraft above ground datum, makes it possible to determine the representative fraction (RF) or natural scale:

$$RF = \frac{\text{Focal length (ft.)}}{\text{Flying height above ground (ft.)}}$$

The height of the aircraft is rarely known to the interpreter, however, and photo scale is more often calculated by this proportion:

$$RF = \frac{\text{Photographic distance between two points (ft.)}}{\text{Ground distance between same two points (ft.)}}$$

Determining scale from ground measurements.--Select two points on opposite sides of the photo so that a line connecting them passes near the PP. If the points are approximately equidistant from the PP, the effect of photographic tilt[3/] (which may be present but not apparent) will be minimized. Points must be easily identifiable on the ground so that the distance between them can be precisely measured. Gas and power line rights-of-way, highways, and railroads offer clearings where ground distances can be quickly chained. It is not essential to calculate the scale of every photograph in a flight strip. In hilly terrain, every third or fifth print may be used; in flat topography, every tenth or twentieth. Scales of intervening photos can be obtained by interpolation (10).

Office checks of photo scale.--Scale determination from ground measurements is laborious and expensive; hence other methods should be used wherever possible. If a U. S. Geological Survey quadrangle sheet is available, the map distance can be measured and substituted as the ground distance in the formula, provided the same distance can be identified for photo measurement.

Another alternative is presented in areas of flat terrain where General Land Office subdivisions of sections, quarter-sections, and forties are visible on the photographs. Since the lengths of these subdivisions will be known, they can also be used as ground distances. A given section may rarely be exactly 5, 280 feet on a side, but determining scale by this method is more accurate than accepting the nominal scale (fig. 1).

3/ Resulting from deviation of the camera axis from the vertical at the instant of film exposure.

Compass bearings and distances.--Although flight lines usually run North-South or East-West, few photographs are oriented exactly with the cardinal directions. For this reason, a reference line must be located before bearings can be determined. The method below is used by field teams on the Southern Forest Survey:

(1) Select a straight-line feature on the photo such as a highway, section line, or field edge and determine its bearing. Draw this reference line on the photograph, extend it as necessary, and record the bearing.

(2) Pick a point of beginning from which the line of approach to a field location will be run. This should be some feature visible on both photo and ground, such as a fence corner, barn, road intersection, or stream fork. Draw a line on the photograph from the beginning point to the location, and extend until it intersects the reference line. Measure the angle between the two lines with a protractor and determine the bearing of the line of approach.

(3) Measure the distance between the point of beginning and the field location to the nearest 0.01 inch and convert to feet or chains at the calculated photo scale. At a scale of 1:20,000 a measure of 0.01 inch equals 16.67 feet or about 25 links. Common scale conversions are given in table 1.

Table 1.--*Useful conversions for common photo scales*

Photo scale (RF)	Feet per inch	Chains per inch	Inches per mile	Acres per square inch	Diameter of one-acre plot	Diameter of 1/5-acre plot
					Inch	*Inch*
1:14,000	1,167	17.68	4.53	31.25	0.202	0.090
1:15,000	1,250	18.94	4.22	35.87	.188	.084
1:15,840	1,320	20.00	4.00	40.00	.178	.080
1:16,000	1,333	20.20	3.96	40.81	.177	.079
1:17,000	1,417	21.46	3.73	46.07	.166	.074
1:18,000	1,500	22.73	3.52	51.65	.157	.070
1:19,000	1,583	23.99	3.33	57.55	.149	.067
1:20,000	1,667	25.25	3.17	63.77	.141	.063
1:21,000	1,750	26.52	3.02	70.31	.135	.060
1:22,000	1,833	27.78	2.88	77.16	.128	.057
Formula calculation[1]	$\frac{RFD}{12}$	$\frac{RFD}{792}$	$\frac{63,360}{RFD}$	$\frac{(RFD)^2}{6,272,640}$	$\frac{2826.0526}{RFD}$	$\frac{1263.8491}{RFD}$

[1] RFD = Representative fraction denominator, as 20,000.

IDENTIFYING FOREST TYPES AND PREPARING BASE MAPS

FOREST TYPES

Forest type boundaries can usually be delineated with greater accuracy and lower cost on aerial photographs than by ground methods. The degree to which species groups can be recognized depends on the quality and age of photography, type of film used, and the interpreter's experience. Most USDA photography shows little tonal contrast between various forest types. Thus the interpreter must rely largely upon photographic texture, topographic position, season of photography, and a knowledge of forest associations on the ground to make reliable type distinctions.

The wise interpreter will delineate only those types that he can consistently recognize. For maximum accuracy, type lines should be drawn under the stereoscope. A china-marking pencil is recommended for preliminary work, as lines are easily removed with carbon tetrachloride or benzene. Water-soluble ink is also suitable. Permanent markings can be made with drawing ink, after types have been verified by ground reconnaissance.

In figures 7 to 12, several southern forest types are illustrated on 1:20,000 USDA panchromatic photography. Single prints are used because of the difficulty of reproducing high-quality stereograms.

PREPARING TYPE MAPS

Type maps are no longer considered essential by all foresters, but at times their cost may be justified. A general ownership map showing principal roads, streams, forest types, and condition classes may be desired for management planning and illustrative purposes. Or in making a photo-controlled ground cruise where precise forest-area estimates are required, it may be necessary to measure stand areas on controlled maps of known scale rather than directly on contact prints. This is particularly important where topography causes wide variation in photo scales.

Uncontrolled maps.--Where area measurement is not critical, simple uncontrolled type maps can be prepared at photo scale by direct tracing. The property boundaries are drawn within the "effective area"[4/] of alternate prints in each flight strip. Photos are interpreted under the stereoscope, and all types and planimetric data are outlined. The detail is then traced onto frosted acetate or vellum, using one annotated print at a time. If property boundaries are accurately drawn on interpreted prints to include all of the tract without duplication, the traced data from adjoining prints should match

4/ If 9- by 9-inch photographs with 60 percent endlap and 30 percent sidelap are assumed, alternate photos will have effective areas of about 3.6 by 6.3 inches.

Figure 7.--*Loblolly-shortleaf pines* predominate here, exhibiting a fine texture and dark tone. The left photograph was made in winter, the other in late spring when hardwood foliage was partially developed. Loblolly pine will often be found at lower elevations on moist sites, while shortleaf is more common on slopes and ridges, but separation of the two species in mixture is not feasible.

Figure 8.--Mixtures of *loblolly-shortleaf pines and hardwoods* are difficult to recognize on summer panchromatic photography (left), but the dark-toned pines are easily distinguished on winter photos (right). The hardwood component is generally of the upland variety, such as the oaks and hickories, but loblolly and pond pine may be mixed with bottomland hardwoods in the Coastal Plain.

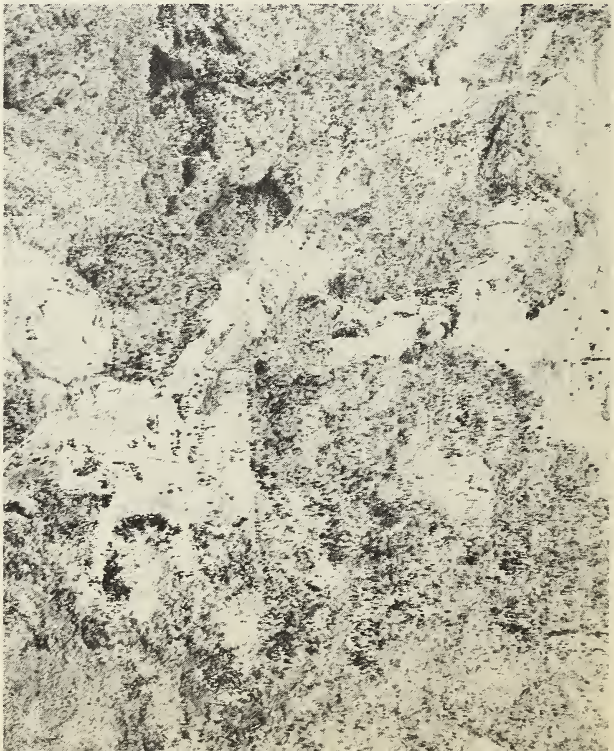


Figure 9.--*Upland hardwoods* can generally be separated from bottomland hardwoods by lighter tones and location at higher elevations. Stands photographed during the growing season (left) exhibit a characteristic rough texture as compared with conifers. Accurate photo measurements are difficult when trees are leafless (right).

Figure 10.--*Bottomland hardwoods* are found along river bottoms and other low areas, notably the Mississippi Delta. Sites are characterized by meandering streams, oxbow lakes, and standing water. Dense stands and wet ground may make photographic tones darker than for upland hardwoods. The left photo was made during the growing season; stands on the right are leafless. The fine-textured area in the upper left of the winter photo is willow and cottonwood on a recent deposition of sand and silt.

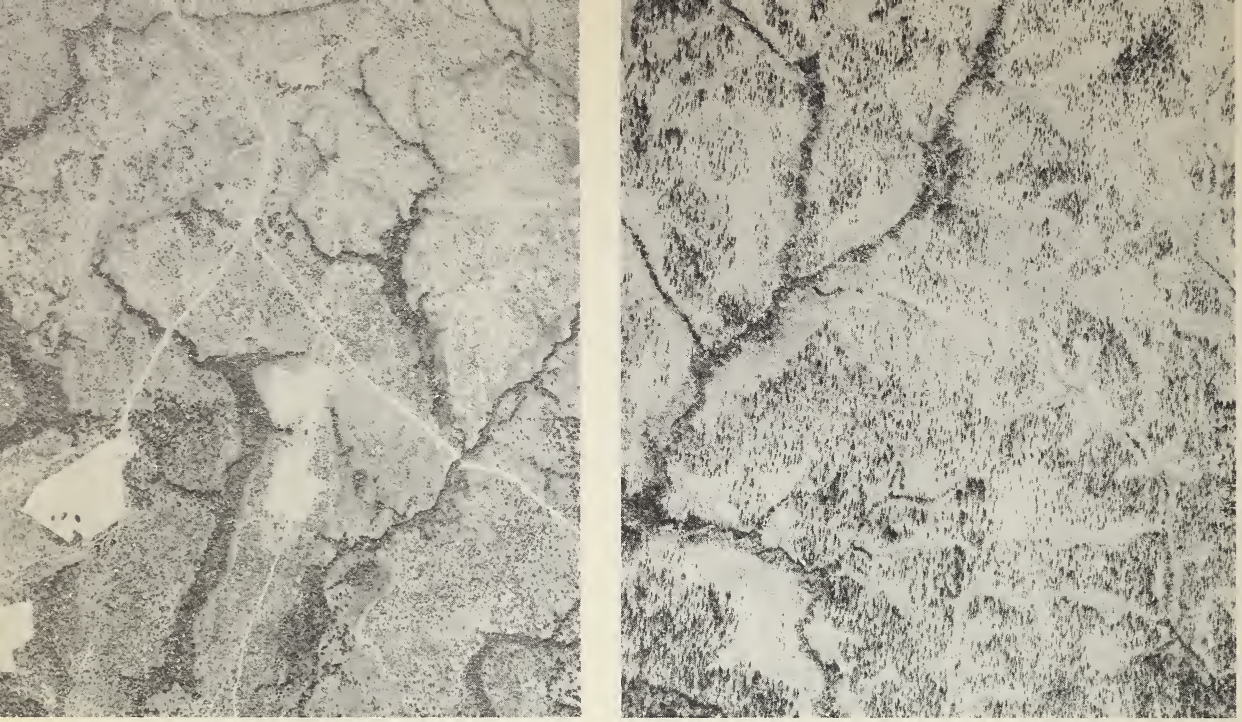


Figure 11.--*Longleaf-slash pines* are commonly found on broad, sandy ridges of the Coastal Plain, separated by dark, dense zones of hardwoods which follow dendritic drainage patterns. Stands are open, often sparsely stocked, with little understory vegetation obscuring the ground. Shadows of young trees are distinctly pointed. Slash pine shows up in darker tones than longleaf, but the two species are not generally separable on panchromatic photography. The left photograph was taken in summer, the right in winter, as evidenced by lack of foliage in hardwood bottoms.

up without difficulty. To assure standardization in type recognition, it is desirable to have one man perform all interpretation work.

For area measurement, uncontrolled maps are no more accurate than the photographs from which they were prepared, but they may suffice for management plans and illustration. In the many areas of the South where flat terrain predominates, average photo scales vary only slightly, and photo tracings may approach the accuracy of controlled maps.

Controlled maps.-- Base maps of uniform scale may be required for photo-controlled ground cruises, as precise measures of forest area by type and stand-size are essential for accurate volume estimates. In flat terrain average photo scale can be determined and acreages measured directly on contact prints, but in steep topography variations in photo scale require the transfer of forest types to base maps for accurate area measurement. The most common way of adjusting variable photo scales to controlled maps is by constructing "radial line plots" or by preparing plat sheets from field notes of the General Land Office. As construction of a radial line plot is quite complex and has been adequately treated in several readily available publications (1, 17, 18), it will not be reviewed here.

Figure 12.--*Slash pine* plantations in the upper Coastal Plain. Rows are still visible though some thinnings have been made.

Figure 13.--*Non-forest* land uses can also be recognized on aerial photographs. The central area of this photo shows land which has been recently cleared, with stumps and tops pushed into windrows. Cultivated fields surround the new clearing, with bottomland hardwoods in low depressions and along the river.

General Land Office (GLO) plats.--Most of the United States west of the Mississippi River and north of the Ohio River, plus Alabama, Mississippi, and portions of Florida, was originally subdivided under the U. S. Public Land Survey. Township, range, and section lines are often visible on aerial photographs. If enough such lines and corners can be identified, GLO plats can be constructed as base maps from field notes available at State capitols or county offices. The accuracy of this method depends upon the number of grid lines and corners which can be pin-pointed on the aerial photographs. The technique described is adapted from Johnson (7).

A GLO plat is drawn to average photo scale from field notes, showing sections, quarter-sections, and forties. As many of the same lines and corners as possible are pin-pointed on the aerial photographs, preferably arranged in a systematic framework throughout the forest property. Ownership maps, county highway maps, and topographic quadrangle sheets may be helpful in identification of such corners, but additional points must usually be found by taking the photographs into the field.

When photo interpretation of forest types has been completed, the detail is transferred to the plat, one square of the grid being completed at a time. If the plat and photos are of the same scale, transfer can be made by direct tracing on a light table (fig. 14); where scales differ, a proportionate grid system can be used. Photo detail is forced into corresponding squares on the base map. Transfer of detail should not be extended outside of the framework of control, as large errors may result.

Topographic and county maps.--Topographic quadrangle sheets and county highway maps are often useful in preparing base maps and identifying features on aerial photographs. When available, 7-1/2 minute quadrangle maps at a scale of 1:24, 000 provide excellent base maps, and can be purchased for about 30 cents per copy. State index maps showing areas covered can be obtained free. For information on States west of the Mississippi River, write:

U. S. Geological Survey
Distribution Section
Federal Center
Denver, Colorado

For areas east of the Mississippi River, write:

U. S. Geological Survey
Distribution Section
Washington 25, D. C.

Mail orders must be accompanied by payment in advance. Other sources of topographic quadrangle maps are the Maps and Surveys Branch of the Tennessee Valley Authority, Chattanooga, Tennessee; and the Mississippi River Commission, U. S. Army Corps of Engineers, Vicksburg, Mississippi.

County maps, usually obtainable from State highway departments, may serve as base maps where a high level of accuracy is not required. They show township, range, and section lines, in addition to geographic coordinates (longitude and latitude) to the nearest 5 minutes. County maps are usually printed at a scale of about one-half inch per mile. Although bearings of section lines are not shown, such maps are more reliable than over-simplified plats showing idealized sections oriented exactly with the cardinal directions. Portions of county maps can be enlarged to photo scale and sections subdivided into quarters or forties by proportionate measurement. These maps may be especially helpful in preparing GLO plats as previously outlined.

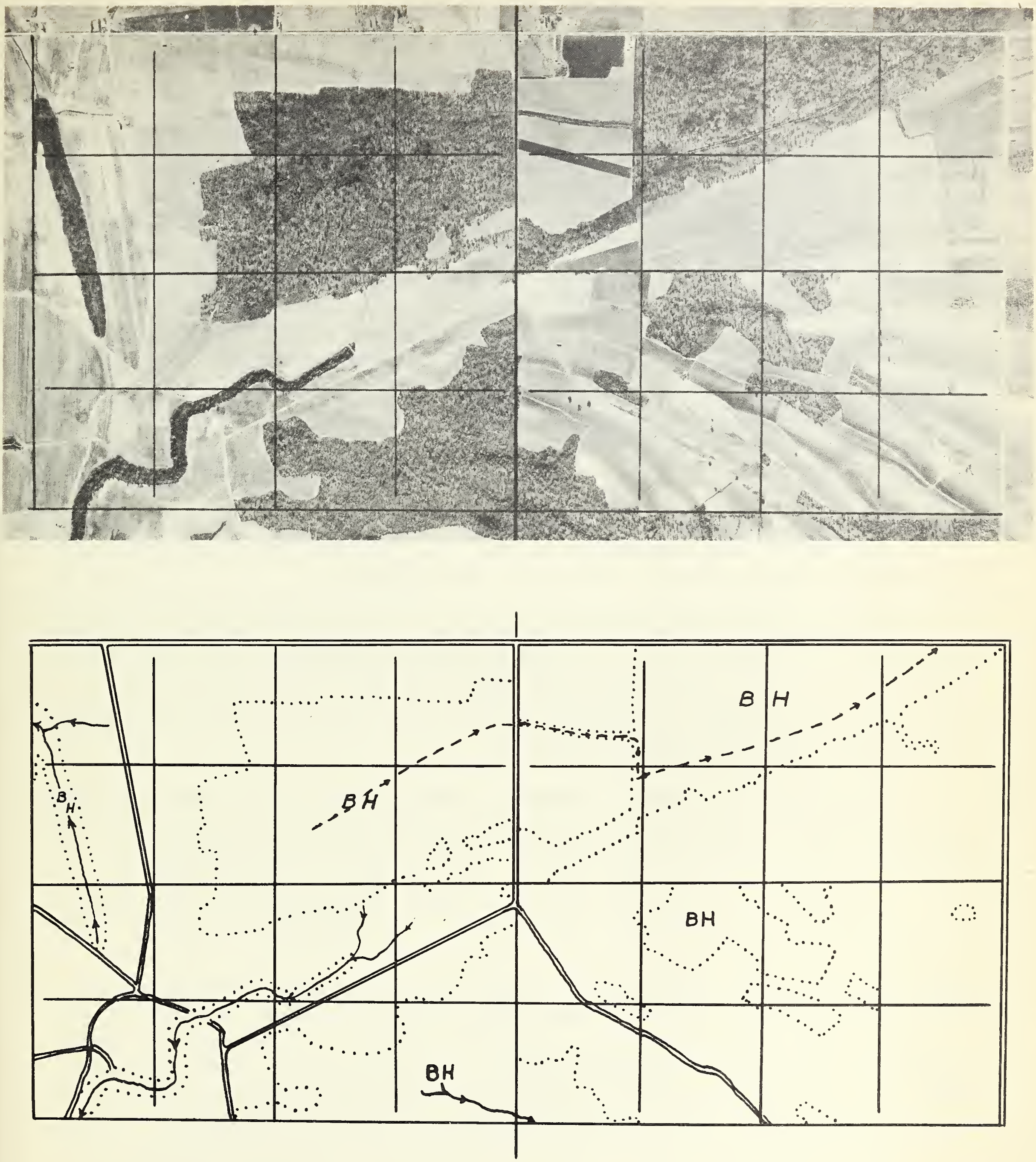


Figure 14.--Portion of aerial photograph covering two sections of land and corresponding type map traced on a GLO grid system. Small squares are forties. Original scale 1:20,000. BH indicates bottomland hardwood types.

MEASURING AREAS

Accurate measures of forest areas are required in both aerial and ground cruising, and photographs offer an inexpensive means of making such determinations. In most of the South, photo scales are not appreciably altered by topographic changes and areas can be measured directly on contact prints. Greater accuracy is possible if forest types are transferred to controlled base maps for area determination, and this procedure may be essential for reliable measurements in mountainous terrain. On the other hand, if only relative proportions of forest types are needed and measurements are limited to the effective area of contact prints, no bias results from using the photographs even when local relief ranges from 1,000 to 2,000 feet (14, 19). This means that for large tracts errors in measurement of areas below the datum plane are compensated by errors of a similar magnitude for areas above the datum plane. For small tracts on rough topography, measurement on controlled maps is recommended. In either case, techniques are quite similar, so that procedures outlined for measuring areas on photographs generally apply to map determinations as well.

Devices for area measurement.--The principal devices for area measurement are polar planimeters, transects, and dot grids.

The planimeter is relatively expensive, and its use somewhat tedious. The pointer is carefully run around the boundaries of an area in a clockwise direction two or more times (for an average reading). From the vernier scale, the area in square inches is read and converted to desired units, usually acres, on the basis of photo or map scale.

The transect method is analogous to determining forest area by a strip cruise in which the chainage encountered in each forest type is recorded. An engineer's scale is aligned on the photos so as to cross topography and drainage at approximately right angles. The length of each type along the scale is recorded to the nearest tenth of an inch. Proportions are developed by relating the total measure of a given type to the total linear measure. For example, if six equally spaced parallel lines 6 inches long are tallied on a given photograph, the total transect length is 36 inches. If bottomland hardwood types are intercepted for a total measure of 7.2 inches, this particular type would be assigned an acreage equivalent to 7.2 ÷ 36, or 20 percent of the total area. The transect method is simple and requires a minimum of equipment. For making rough area estimates on photo index sheets, special transparent overlays for location of transect lines can be improvised (9).

The preferred method of determining area on aerial photographs is with dot grids. These are transparent overlays with dots systematically arranged on a grid pattern. The grid is oriented with the photo fiducial marks to avoid positioning bias, and dots are tallied for each forest type (fig. 15). Type areas are calculated by proportions; the number of dots falling on a

given type divided by the total number counted yields a percentage value that is multiplied by the total area to obtain the type acreage. If the total acreage is not known, the number of acres per square inch is determined. This figure is divided by the number of dots per square inch to get the number of acres represented by each dot.

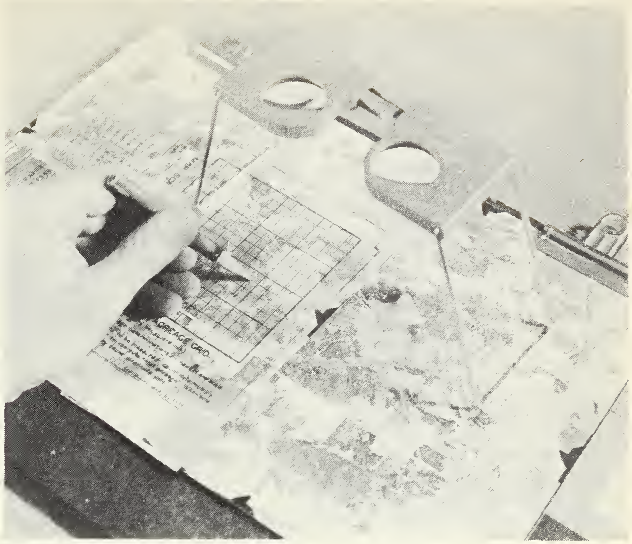


Figure 15.--Using a dot grid to measure forest areas on 1:20,000 aerial photographs. Tallied dots can be checked off with a china-marking pencil to avoid omissions or duplicate counts.

Intensity of dot sampling.--The number of dots that must be counted for a given accuracy depends upon the estimated proportion of the total area occupied by the most important type. If precise acreages are needed for pine sawtimber and such stands occupy about 25 percent of the gross area, the dot intensity would be calculated on this basis. An example is cited from the Forestry Handbook[5/] (17):

Total number of dots to be counted (N) = $\frac{P(1-P)t^2}{(AE)^2}$, where

P = estimate of proportion of area in most important class (25 percent)

AE = allowable error, expressed as a decimal (in this case 0.005)

t = constant reflecting reliability of the estimate (for correctness 19 out of 20 times, t = 1.96)

Thus, $N = \frac{0.25\ (1.00-0.25)\ (1.96)^2}{(0.005)^2} = 28,812$ dots

It is necessary to count a total of 28,812 dots to accurately determine the area of sawtimber stands within the allowable error. The greatest number of dots will be required when P is set at 50 percent, but the count can be considerably reduced if the allowable error is increased. If 0.05 rather than 0.005 is used, only 1/100 as many dots need be counted. The number of dots per square inch is calculated by dividing the total (28,812) by the gross area of the tract in square inches. If 900 square inches are involved, 28,812÷900 = 32

5/ FORESTRY HANDBOOK, edited by Reginald D. Forbes and Arthur B. Meyer, for the Society of American Foresters. Copyright 1955, The Ronald Press Company.

dots per square inch. Here it would be most expedient to use an existing grid with 36 dots per square inch.

For tracts of 1,000 acres or less, grids with closely spaced dots are recommended. Grids with 64 dots per square inch are commonly used with 1:20,000 photographs. Since one square inch equals 63.77 acres at photo scale, each dot represents 0.996 acres. For 1:15,840 photography, where one square inch equals 40 acres, grids with 40 dots per square inch are available. It is not essential that a separate grid be used for each photo scale or that the number of dots per square inch be equal to the acreage per square inch. Counts made with grids of any dot intensity can be converted to acreages by simple proportions.

Dot grids for use with different photo scales can be purchased inexpensively or improvised by pricking needle holes at desired intervals in a sheet of clear cellulose acetate. Counts can also be made with ordinary cross-section paper. The photograph is placed on a tracing table with a strong light underneath and the cross-section paper positioned over the photo. Grid intersections are used as dots, and type percentages calculated by relating the number of intersections in each type to the total number counted. This method will work best when type lines have been previously delineated, and when thin, translucent graph paper is available.

TREE HEIGHT, CROWN DIAMETER, AND CROWN CLOSURE

TREE HEIGHT

Tree heights are commonly determined on aerial photographs by measurements of stereoscopic parallax or shadow lengths. Though more difficult for the beginner, the parallax method is faster, requires fewer calculations, and is more adaptable to a variety of stand conditions. Anyone who can use a stereoscope can train himself to measure stereoscopic parallax, and even the occasional interpreter will find this method of measuring heights advantageous.

Shadow-length measurements are reliable only in open-grown stands where individual shadows fall on level ground. Accurate measurement is almost impossible in dense, irregular stands or on slopes. Furthermore, the conversion of photo shadow length to tree height is quite complex in comparison to the conversion of parallax measurements. For these reasons, only the parallax method will be discussed. Foresters interested in details of shadow-height calculations should refer to Johnson's article (8), which includes a special form for making tree-height conversions.

The concept of parallax.--As defined in the Manual of Photogrammetry (1), parallax as a general term is "the apparent displacement of the position of a body with respect to a reference point or system, caused by a shift in the point of observation." In measuring object heights on stereoscopic pairs of aerial photographs, two types of parallax must be measured or approximated. The absolute stereoscopic parallax of a point is "the algebraic difference, parallel to the air base, of the distances of the two images from their respective principal points." The parallax difference, or differential parallax, of an object being measured for height determination is the difference in the absolute stereoscopic parallax at the top and the base of the object, measured parallel to the air base, or flight line (18).

The basic formula for conversion of parallax measurements on aerial photographs is:

$$h = \frac{H \times dP}{P + dP}$$

where h = height of measured object in feet
H = height of aircraft above ground datum in feet
P = absolute stereoscopic parallax in inches
dP = parallax difference in inches

For substitution in this formula, the height of the aircraft above ground datum is calculated from the basic scale formula, transposed to the more convenient form: Flying height (H) = focal length x scale denominator. With photographs of 1:20,000 scale and a camera of 8-1/4 inch focal length, the flying height would be 0.6875 x 20,000 = 13,750 feet.

In flat terrain, the average photo base length is ordinarily substituted as the absolute stereoscopic parallax (P) in the formula. If the ground elevation at the base of the tree being measured differs from the elevation of the principal points by more than 200 or 300 feet, however, the following method, as outlined in the Forestry Handbook[6/] (17), should be used to calculate a new value for P:

(1) Orient the stereo-pair with flight lines superimposed and photo images separated about 2 to 2-1/4 inches. Clip down photographs.

(2) Measure distance between the two principal points to the nearest 0.01 inch with an engineer's scale.

(3) Measure the distance between corresponding images on the two photographs at or near the base of the tree to the nearest 0.01 inch.

(4) Subtract (3) from (2) to obtain the absolute stereoscopic parallax at the base of the tree.

The parallax difference (dP) is measured stereoscopically with a parallax wedge or parallax bar, both devices employing the "floating mark" principle.

Parallax wedges.--Parallax wedges are usually printed on transparent film or glass. The basic design consists of two rows of dots or graduated lines beginning about 2.2 inches apart and converging to about 1.8 inches apart. The graduations on each line are calibrated for making parallax readings to the nearest 0.002 inch (fig. 16).

In use, the parallax wedge is placed over the stereoscopic image with the converging lines perpendicular to the line of flight and adjusted until a single fused line of dots or graduations is seen sloping downward through the stereoscopic image. If the photo images are separated by exactly 2 inches, a portion of the parallax wedge centering around the 2-inch separation of converging lines will fuse and appear as a single line. The line will appear to split above and below this section. Using the fused line of graduations, the parallax difference is obtained by counting the number of dots or intervals between the point where a graduation appears to rest on the ground and the point where a graduation appears to "float" in the air at the same height as the top of the tree. If each graduation denotes 0.002 inch parallax, and there are six graduations between the point at ground level and tree top level, the parallax

6/ FORESTRY HANDBOOK, edited by Reginald D. Forbes and Arthur B. Meyer, for the Society of American Foresters. Copyright 1955, The Ronald Press Company.

difference (dP) of 0.012 inch would be substituted in the basic parallax formula. Where P is large in relation to dP, tables 2 and 3 can be used as short-cut approximations in converting parallax measurements to tree heights.

The parallax bar.--This instrument[7] is more expensive than the parallax wedge and yields results of the same order of accuracy, but many photo interpreters prefer it because the floating dot is movable for easier placement on the ground and at crown levels. The bar can also be attached to the legs of the lens stereoscope, assuring parallel movement of the two instruments (fig. 17).

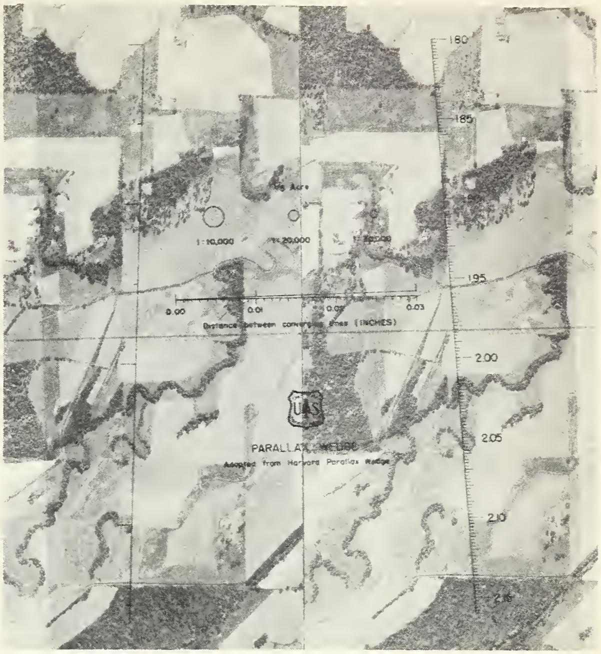
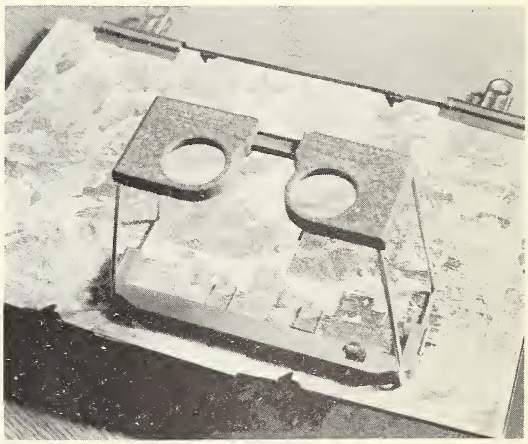


Figure 16.--Parallax wedge correctly oriented over a stereogram with converging lines perpendicular to the line of flight. Graduations on right-hand line refer to separation of the two lines in inches.

The bar has two transparent lenses attached to a metal frame that houses a vernier and a graduated metric scale. The left lens contains the fixed reference dot while the dot on the right lens can be moved laterally by means of the vernier. The bar is placed over the stereoscopic image parallel to the line of flight. The right-hand dot is moved until it fuses with the reference dot and appears to rest on the ground at the base of the tree. The vernier reading is recorded to the nearest 0.01 millimeter. The vernier is then turned until the fused dot appears to "float" at tree-top level and a second reading recorded. The difference between the readings is the parallax difference (dP) in millimeters. This

Figure 17.--Parallax bar attached to legs of lens stereoscope and correctly aligned with long axis parallel to line of flight. The right-hand lens is movable laterally by means of the knurled cylinder.



7/ The particular instrument discussed is manufactured by the Abrams Instrument Co., Lansing, Michigan. Other suitable makes may be available.

Table 2.--*Parallax-wedge conversion factors*[1] *for wedges reading to 0.002 inch parallax (dP)*

Photo base P (inches)	Height per 0.002 inch of dP, for scales (RF) of--				
	1:18,000	1:19,000	1:20,000	1:21,000	1:22,000
	- - - - - - - - - - - *Feet* - - - - - - - - - -				
2.60	9.5	10.0	10.6	11.1	11.6
2.70	9.2	9.7	10.2	10.7	11.2
2.80	8.8	9.3	9.8	10.3	10.8
2.90	8.5	9.0	9.5	10.0	10.4
3.00	8.2	8.7	9.2	9.6	10.1
3.10	8.0	8.4	8.9	9.3	9.8
3.20	7.7	8.2	8.6	9.0	9.4
3.30	7.5	7.9	8.3	8.7	9.2
3.40	7.3	7.7	8.1	8.5	8.9
3.50	7.1	7.5	7.9	8.2	8.6
3.60	6.9	7.3	7.6	8.0	8.4
3.70	6.7	7.1	7.4	7.8	8.2
3.80	6.5	6.9	7.2	7.6	8.0
3.90	6.3	6.7	7.0	7.4	7.8
4.00	6.2	6.5	6.9	7.2	7.6

[1] Assumes camera focal length of 8¼ inches. To enter table, determine average photo base length and scale, and measure parallax difference of tree. If base length is 3.60 inches, RF = 1:21,000, and dP = 0.012 inch (6 dots on wedge), height = 6 x 8 or 48 feet.

Table 3.--*Parallax-bar conversion factors*[1] *for use with devices reading to 0.01 mm parallax (dP)*

Photo base P (inches)	Height per millimeter of dP, for scales (RF) of --				
	1:18,000	1:19,000	1:20,000	1:21,000	1:22,000
	- - - - - - - - - - - *Feet* - - - - - - - - - -				
2.60	185	195	205	215	226
2.70	178	188	198	208	217
2.80	172	181	191	200	210
2.90	166	175	184	193	203
3.00	160	169	178	187	196
3.10	155	164	172	181	190
3.20	150	159	167	175	184
3.30	146	154	162	170	178
3.40	142	150	157	165	173
3.50	138	145	153	161	168
3.60	134	141	149	156	164
3.70	130	138	145	152	159
3.80	127	134	141	148	155
3.90	124	131	137	144	151
4.00	121	127	134	141	147

[1] Assumes camera focal length of 8¼ inches. To enter table, determine average photo base length and scale, and measure parallax difference of tree. If base length is 3.00 inches, RF = 1:19,000, and dP = 0.38 millimeter, height = 0.38 x 169 or 64 feet.

value can be substituted in the parallax formula without conversion if the absolute parallax (P) is also expressed in millimeters.

Accuracy of height measurements.--Accuracy in measuring total heights of trees and stands depends upon a number of factors, not the least of which is the ability of the individual in determining stereoscopic parallax. Most interpreters can detect differences in parallax of about 0.002 inch, and this graduation interval is used on most parallax wedges.

The photo interpreter who can detect a difference of 0.002 inch of stereoscopic parallax will be able to stratify forest stands into 10-foot total height classes on contact prints of 1:15,840 to 1:20,000 scales (18). Greater accuracy in height measurement may be possible in flat terrain where photo scale changes are not pronounced and less skill is required in selecting the point for the base parallax reading. Care must be exercised to make the ground parallax reading on the same contour as the base of the tree.

The interpreter should consider the points below as a means of improving accuracy in height measurement:

In rough terrain, the calculation of a new photo scale and flying height for each overlap is desirable. For stands on high ridges or in deep ravines, it is better to calculate new values for absolute stereoscopic parallax than to use the average photo base length.

Once a pair of photographs has been aligned for stereo-viewing, they should be fastened down to avoid movement. A slip of either photograph between the parallax reading at the base and the top of a tree may yield highly inaccurate height readings.

To avoid single measurements of high variability, it is recommended that several measurements be made of the same tree or stand, and the results averaged (11).

TREE CROWN DIAMETER

Crown diameters are measured with wedges or dot-type scales reading in thousandths of an inch. With a crown wedge, the diverging lines are placed tangent to either side of the crown for making the reading. Dot-type scales have circles of graduated sizes for direct comparison with tree crowns. (fig. 18). For converting measurements, the scale of photography is calculated in

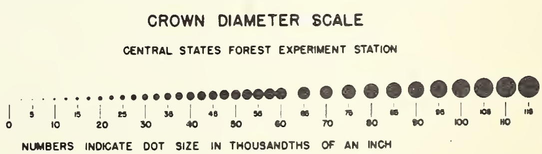


Figure 18.--Dot-type crown-diameter scale. Such scales are printed on transparent film.

Table 4.--*Actual crown width for various photo-crown widths and photo scales*[1]

Photo crown width (thousandths of an inch)	1:18,000	1:19,000	1:20,000	1:21,000	1:22,000
	Feet	*Feet*	*Feet*	*Feet*	*Feet*
2.5	4	4	4	4	5
5.0	7	8	8	9	9
7.5	11	12	13	13	14
10.0	15	16	17	18	18
12.5	19	20	21	22	23
15.0	22	24	25	26	27
17.5	26	28	29	31	32
20.0	30	32	33	35	37
22.5	34	36	37	39	41
25.0	37	40	42	44	46
27.5	41	44	46	48	50
30.0	45	47	50	53	55

[1] Source: Jensen, C. E. Dot-type scale for measuring tree-crown diameters on aerial photographs. U.S. Forest Serv. Central States Forest Expt. Sta. Sta. Notes 48, 2pp., illus. 1948.

feet per thousandth of an inch. At 1:20, 000, each 0. 001 inch of crown measure equals 1. 667 feet. A reading of 10/1, 000 inch would imply a crown diameter of 17 feet (table 4).

Tree crowns are rarely circular, but because individual limbs are often invisible on aerial photos, they usually appear roughly circular or elliptical. As only the portions of the crown visible from above can be evaluated, photo measures of crown diameter are often lower than ground checks of the same trees. Nevertheless, most interpreters can determine average crown diameter with reasonable precision if several readings are taken and there is no constant bias in measurement.

Obviously, crown diameter measurements of individual trees are most accurate in open-grown stands. In dense stands, measurements are generally confined to determination of an average for the dominant trees. Crowns can usually be classified into five-foot classes without difficulty (18).

TREE CROWN CLOSURE

Crown closure percent, also referred to as crown cover or crown density, is the proportion of the forest canopy occupied by tree crowns. The term may refer to all trees in the stand regardless of canopy level or only to the

dominant stand. Crown closure is often applied in making photo determinations of stand volume. It is estimated ocularly in 10 to 30 percent classes, using printed density scales as an aid (fig. 19). Inexperienced interpreters tend to overestimate crown closure by overlooking small stand openings or including portions of crown shadows. Devices for checking crown closure on the ground are considered unsatisfactory, and the interpreter must rely on practice to develop skill in making photo estimates.

Crown closure is useful because of its relation to stand volume per acre. It is applied in lieu of basal area or number of trees per acre, as these variables cannot be accurately determined on available photography. Measurements of crown diameter and estimates of crown closure percent should always be made under the stereoscope.

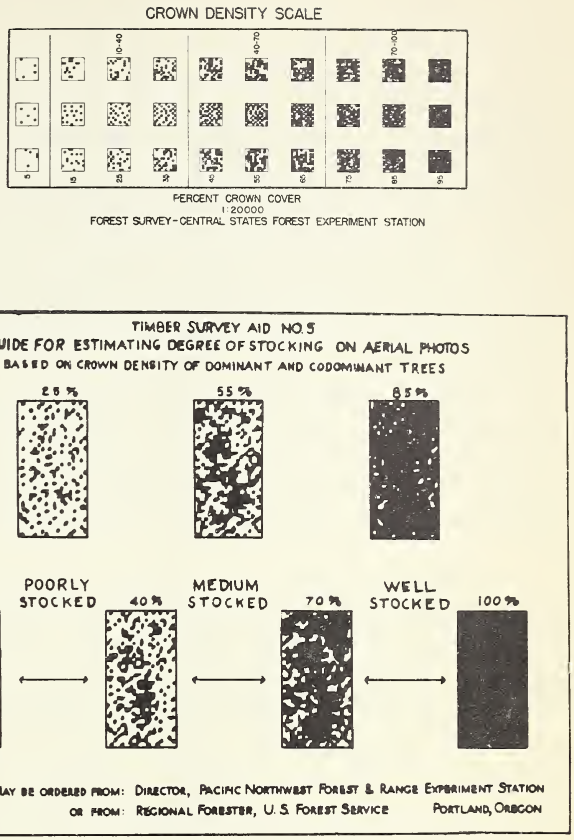


Figure 19.--Two types of density scales for comparison with photo images in estimating tree crown closure.

Tree counts can seldom be made accurately on available aerial photographs. Only in even-aged, open-grown forests can all trees in a stand be separated. Counting all trees on a single plot is tedious, and this measure of density is seldom used. Where large-scale photographs are available (1:1,000 to 1:5,000), individual-tree counts may be much more reliable.

INDIVIDUAL TREE VOLUMES

Where photo volume tables are available, the gross volume of individual trees may be determined on moderate-scale photography of open-grown forest stands. Aerial tree-volume tables are entered by measuring crown diameter and total height. The construction and application of such tables is dependent upon a correlation between photo measures of crown diameter and d. b. h. This relationship can often be established for single species or species groups, notably even-aged conifers in the middle diameter classes (18). Minor (12, 13) developed linear relationships of crown diameter and stem diameter for pine stands in Louisiana and compiled cubic- and board-foot aerial tree-volume tables based on Girard Form Class 80. Two of his cubic-foot tables are included here (tables 5 and 6), along with a suggested form for recording data from individual trees (fig. 20). Photo measurements may include all trees on 1/5- to 1-acre circular plots, or stands can be delineated according to height classes for determination of the average tree per unit area. In the latter instance, a tree count must be made for obtaining the total stand volume.

This method of obtaining volume is applicable only where individual trees can be separated stereoscopically for an accurate measure of total height, crown diameter, and crown counts. Also, there are few aerial tree volume tables which can be applied regionally. In the South, longleaf-slash pine stands offer the best opportunities for aerial cruising of this nature.

State________ County________ T______ R______ Sec.______ Plot______

Photo Nos.________ Photo date________ Av. photo base________ P I date________

Parallax conversion factor__________ Average form class__________

Tree No.	Species		Parallax			Total height	Crown diameter	Tree volume	
	Pine	Hwd.	Base	Top	dP			Board feet	Cubic feet
1									
2									
3									
4									
5									
6									
7									

Figure 20.--Record form for use with individual-tree aerial volume tables.

Table 5.--*Aerial volume table for sawlog-size longleaf pine trees of Form Class 80*[1]

Crown diameter (feet)	Total visible height 50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	110 feet
	- - - - - - - *Cubic feet, inside bark*	- - - - - - -					
10	9.15	10.17	11.19	12.20	13.22		
12	11.53	12.88	14.41	15.93	17.46	18.81	
14	13.72	15.70	17.68	19.67	21.49	23.47	25.45
16		18.87	21.29	23.87	26.29	28.87	31.29
18		21.69	24.77	27.69	30.77	33.85	36.77
20		25.61	29.24	32.88	36.67	40.30	43.94
22		29.70	34.18	38.51	42.84	47.16	51.49
24			39.41	44.41	49.56	54.71	59.85
26			45.25	51.24	57.08	63.07	69.05
28			51.59	58.40	65.22	72.17	78.09
30			58.27	66.04	73.81	81.73	89.50

[1] Reprinted from *(13)*. Basis: 60 longleaf pines measured in southeast Louisiana.

Table 6.--*Aerial volume table for sawlog-size loblolly, slash, and shortleaf pine trees of Form Class 80* [1]

Crown diameter (feet)	Total visible height 50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	110 feet
	- - - - - - - - - *Cubic feet, inside bark*	- - - - - - - - -					
10	10.9	13.0	15.2	17.4	19.6		
12	13.3	17.0	18.5	21.1	24.1	26.7	
14	16.3	19.7	22.7	26.0	29.3	32.7	36.0
16		22.6	26.2	30.0	33.8	37.6	41.5
18		26.2	30.5	34.9	39.5	43.8	48.1
20		30.0	35.0	40.0	45.0	50.0	55.0
22		34.5	40.2	46.0	51.9	57.6	63.3
24			45.7	52.3	58.9	65.4	72.0
26			50.2	57.4	64.7	71.9	79.2
28			55.9	63.9	72.0	80.0	88.0
30			61.8	70.6	79.4	88.2	97.1

[1] Reprinted from *(13)*. Basis: 200 trees measured in southeast Louisiana and southwest Mississippi.

If recent photographs and reliable aerial stand-volume tables can be obtained, average stand volume per acre can be estimated with a minimum of field work. Estimates are made in terms of gross volume, as amount of cull or defect cannot be adequately evaluated. Even-aged stands of simple species structure are best suited for this type of estimate, especially where gross and net volumes are essentially identical. All-aged stands of mixed hardwoods are more difficult to assess, but satisfactory results can be obtained where field checks are made to adjust the photo estimate of stand volume per acre and make allowance for defect. Though photo volumes cannot be expressed by species and diameter classes, total gross volumes for areas as small as 40 acres can be estimated within 10 percent of ground volumes (15).

Most aerial stand-volume tables for mixed species are constructed in terms of cubic feet per acre. Tables for species occurring naturally in pure stands, such as longleaf pine, may be expressed either in board feet or cubic feet per acre. The three photographic measurements generally required for entering an aerial stand volume table are:

Average total height of the dominant stand.
Average crown diameter of the dominant stand.
Average crown closure percent of the dominant stand.

In some tables, crown diameter is eliminated as a variable and only the other two items are required.

It is desirable to have aerial stand-volume tables for all species groups that can be consistently separated on available photography. The only published tables for southern timber, however, are a cordwood table for loblolly and slash pine in Louisiana (13) and a cubic-foot table for Kentucky hardwoods (16). These tables are included (tables 7 and 8), along with a form for re-

Table 7.--*Aerial photo stand-volume table for Louisiana loblolly and slash pines* [1]
(Pulpwood volume in standard rough cords per acre,[2] *trees of average Form Class 77)*

Average total visible height (feet)	Crown closure, all trees 5 inches d.b.h. and up to variable top diameter								
	15 percent	25 percent	35 percent	45 percent	55 percent	65 percent	75 percent	85 percent	95 percent
30	2.7	4.5	6.3	8.2	10.0	11.8	13.6	15.4	17.2
40	3.6	6.1	8.5	10.9	13.4	15.8	18.2	20.7	23.1
50	4.6	7.6	10.7	13.7	16.8	19.8	22.9	25.9	29.0
60	5.5	9.2	12.9	16.5	20.2	23.9	27.5	31.2	34.9
70	6.4	10.7	15.0	19.3	23.6	27.9	32.2	36.5	40.8
80	7.4	12.3	17.2	22.1	27.0	31.9	36.8	41.8	46.7

[1] Compiled from original data by C. O. Minor, School of Forestry, Louisiana State University, 1953. Based on 57 plots from southeastern Louisiana.
Volume of trees 4.6 inches and up = (0.62 height − 0.48) x density.
Correlation coefficient (r) = + 0.90.
Standard error of estimate = 2.2.

[2] Rough conversion to cubic feet per acre can be made by multiplying volumes by 75.

Table 8.--*Gross cubic-foot volume per acre for Kentucky hardwood stands by average stand height, crown diameter, and crown coverage*[1, 2, 3]

10- to 14-FOOT CROWN DIAMETER

Average stand height (feet)	Crown cover 15 percent	35 percent	55 percent	85 percent
	- - - - - - - - 10 cubic feet - - - - - - -			
30	30	45	50	70
40	35	50	60	75
50	40	55	70	90
60	55	80	95	120
70	90	125	140	160

15- to 19-FOOT CROWN DIAMETER

Average stand height (feet)	15 percent	35 percent	55 percent	85 percent
30	35	45	55	75
40	40	50	65	85
50	45	60	75	100
60	60	85	105	120
70	100	130	150	165
80	150	175	190	210

20- to 29-FOOT CROWN DIAMETER

Average stand height (feet)	15 percent	35 percent	55 percent	85 percent
40	50	75	95	120
50	60	90	110	135
60	90	120	135	155
70	135	160	175	195
80	175	205	220	240
90	220	250	265	285
100	270	300	315	330

30+ FOOT CROWN DIAMETER

Average stand height (feet)	15 percent	35 percent	55 percent	85 percent
40	85	120	135	155
50	105	135	150	170
60	130	160	170	195
70	170	200	215	235
80	215	240	260	280
90	260	285	300	320
100	305	330	345	360
110	360	380	395	415

[1] Reprinted from (*16*).

[2] Figures within the blocked areas are based on field data.

[3] Volume to 4-inch top diameter, inside bark.

cording measurements on photo plots (fig. 21). The tables may be used to obtain gross volume in many areas of the South, but the estimates should be adjusted by field samples.

State__________ County__________ T______ R________ Sec.________ Plot__________

Photo Nos.__________ Photo date__________ Av. photo base________ PI date______

Land classification: (Forest) (Cultivated) (Idle) (Pasture) (Water) (Urban) __________

Parallax readings for 5 trees

Reading	Base	Top	dP
1			
2			
3			
4			
5			
	Total dP		
	Average dP		
	Parallax factor		
	Av. total height		
	Total height class (nearest 10 feet)		

Forest type: (P) (P-H) (UH) (BH) (   )

Size class: (Saw) (Poles) (Seed-Saps) (   )

Crown diam. class: (5') (10') (15') (20') (25') (30'+)

Crown closure: (5%) (15%) (25%) (35%) (45%) (55%) (65%) (75%) (85%) (95%)

Gross volume per acre__________

Interpreted by__________________

Figure 21.--Plot record card for use with stand aerial volume tables.

The publication in which the hardwood table originally appeared (16) outlines a procedure by which it can be adapted for use in other areas:

(1) Outline tract boundaries on the photographs, utilizing the effective area of every other print in each flight line. This assures stereoscopic coverage of the area on a minimum number of photographs and avoids duplication of measurements by the interpreter.

(2) Delineate all forest types. Except where type lines define stands of relatively uniform stocking and total height, they should be further broken down into homogenous units so that measures of height, density, and crown diameter will apply to the entire unit. Generally, it is not necessary to recognize stands smaller than 5 to 10 acres in this breakdown.

(3) Determine the acreage of each condition class with dot grids. This can often be done on contact prints.

(4) By stereoscopic examination, measure the variables for entering the aerial stand volume table. From the table, obtain the average volume per acre for each condition class.

(5) Multiply gross volumes per acre from the table by condition class areas to determine gross volume.

(6) Add class volumes for the total gross volume on the tract.

An alternative system of making direct photo volume estimates has been employed by Moessner and Jensen (15). Interpretation is based on a classification of systematically arranged, one-acre circular plots located with a transparent templet.

(1) Outline tract boundaries on photographs and prepare a templet on transparent plastic. Templets usually have 16, 25, or 36 equally spaced, one-acre circles for transferring to the central area of each 9- by 9-inch print. (The number of plots required for an accurate estimate of stand-size acreage can be computed by the formula in the section on area measurement, p. 19.)

(2) Tally all forest plots by type and stand-size. Compute the area of each class by applying proportions to the gross forest acreage.

(3) Interpret all or a portion of the plots to determine the gross volume per acre. Every fifth, tenth, or twentieth plot within each class can be taken, depending on accuracy desired. It is generally advisable to measure 4 to 10 times as many photo plots as would be required for similar accuracy in ground cruising.

(4) Determine the average volume per acre for each type and size class. Multiply by acreage to obtain the gross volume in each class and total volume for the tract.

Adjusting photo volumes by field checks.--When aerial volume tables are not sufficiently reliable for acceptance of pure photo estimates and allowance must be made for defective trees, some of the plots interpreted should be mechanically selected for field measurement. For example, if 350 plots were interpreted and every tenth plot selected, 35 plots would be visited in the field. If the field volumes averaged 600 cubic feet per acre as opposed to 800 cubic feet per acre for the photo plots, the adjustment ratio would be 600÷800 or 0.75. If the 35 field plots are representative of the total, the ratio can be applied to the average photo volume per acre to determine the adjusted volume per acre. It is desirable to compute ratios by stand condition classes, because hardwoods are likely to require larger adjustments than pines.

The accuracy of aerial cruises depends not only upon the volume tables, but on the availability of recent photographs and the ability to make photo measurements correctly. This last item may be the greatest single source of error. It is advisable to measure each photo variable twice for an average, or to have two interpreters assess each plot. Worley and Meyer (11) have pointed out means of reducing interpreter errors in making photo volume estimates.

Photo volume estimates for a single plot are rarely as reliable as the field tally of the same plot. Values in aerial stand-volume tables represent averages for several highly variable plots, all of which may reflect identical photo measurements. Thus photo volumes are reliable only when the average volume per acre of 25 to 50 plots has been computed. The tabulation below illustrates this point. Twenty 1-acre plots in upland hardwood stands were selected for interpretation on 1:20,000 panchromatic aerial photographs. Crown diameter, total height, and crown closure measurements for each plot were applied to table 8 for determination of gross cubic volumes per acre. The twenty plots were then measured in the field for a comparison of estimated and actual volumes. It will be noted that paired plot volumes vary considerably from field values, but that the average volume per acre agrees well.

Plot	Photo measurements			Gross volume per acre	
	Crown diam. class	Total height class	Crown closure	Table 8	Field
	- - - *Feet* - - -		*Percent*	- - *Cubic feet* - -	
1	10-14	30	15	300	154
2	10-14	30	15	300	144
3	10-14	40	35	500	312
4	20-29	70	15	1,350	1,088
5	10-14	30	15	300	342
6	10-14	30	35	450	376
7	15-19	30	35	450	364
8	15-19	50	15	450	310
9	15-19	60	55	1,050	820
10	15-19	70	35	1,300	966
11	20-29	60	15	900	620
12	15-19	80	15	1,500	1,836
13	15-19	50	15	450	736
14	20-29	50	15	600	518
15	15-19	50	55	750	970
16	10-14	40	15	350	406
17	15-19	50	55	750	976
18	15-19	60	35	850	878
19	15-19	40	15	400	392
20	15-19	50	55	750	576
Total volumes				13,750	12,784
Average per acre				687.5	639.2

If these plots are assumed to be typical of all upland hardwood plots interpreted, the field-adjustment ratio of 0.93 (639.2÷687.5) can be applied to correct volumes on other photo plots that are not field-checked. The adjusted volume per acre is then multiplied by the type acreage to obtain the total volume within each stratum.

GROUND CRUISING WITH PHOTOGRAPHIC CONTROL

A photo-controlled ground cruise combines the features of aerial and ground estimating, offering a means of obtaining timber volumes with maximum efficiency. Photographs are used for area determination, for allocation of field samples by forest type and stand-size classes, and for designing the pattern of field work. Tree volumes, growth, cull percents, form class, and other data are obtained on the ground by conventional methods. Johnson (6) has shown that a photo-controlled cruise may increase the efficiency and reduce the total cost of an inventory on tracts as small as 500 acres.

There are two approaches to an inventory of this kind. With the first system, forest types are delineated on the entire tract and transferred to base maps, after which areas are measured on the type map (4, 18). The second method does not require a map; type areas are determined by a classification of photo plots as in aerial cruising. As this approach is basically covered in the preceding section, the type-map method will be outlined here.

Phase I, Photo Interpretation

(1) Delineate tract boundaries on alternate photographs in each flight line. This reduces by one-half the number of photos to be handled later in transferring types to the base map.

(2) Set up a simple coding system such as that below, based on photo variables that can be measured with reasonable accuracy. Do not attempt to make extra fine stratifications that will require guesswork.

Forest type	Code	Total height class	Code	Crown density class	Code
Mixed pine	MP	0-20 ft.	I	5-35 percent	A
Pine-hardwood	PH	21-40 ft.	II	35-65 percent	B
Hardwood	H	41-60 ft.	III	65-100 percent	C
		61+ ft.	IV		

A type designated PH-III-B would indicate a stand of pine-hardwoods, 41 to 60 feet tall, with a density of 35 to 65 percent.

(3) By stereoscopic examination, delineate and code all forest types and stand-size classes down to a minimum of 5 to 10 acres. Make certain that types "tie in" when adjacent photos are overlapped in mosaic fashion. Prints from adjacent flight strips should be viewed with a lens stereoscope as an aid in matching types.

(4) Check as many classifications in the field as possible. This can be done by driving over roads and trails in the area and making code corrections on the photographs with a china-marking pencil. Aerial reconnaissance may be feasible for large tracts (5). Attempt to visit at least one example of each type and stand-size classified; then concentrate on the more difficult identifications. Adjust all types on the basis of field corrections.

(5) Prepare a base map for transfer of photo detail, using existing maps if possible. The process is simplified if the map can be enlarged or reduced to correspond with the average photo scale.

(6) Transfer forest types to the base map as previously outlined. All types will then be reduced to a common scale for precise area measurement. After determining the area of each type and stand-size class, obtain a total acreage for each class that will be sampled with a different intensity in the field.

Phase II, Allocation of Field Samples

The total number of field samples to be taken will generally be determined by basic cost considerations and the productivity of field crews (4, 18). Once the number has been determined, there are several ways in which the samples may be distributed among the various photo classifications:

By area of each class. Though sometimes used, this method is often unsatisfactory, as stands of low value may occupy the greatest acreage, while high-value stands would be insufficiently sampled. The opposite extreme might result if value alone (volume-per-acre classes) was used.

By making a certain percent cruise for each class. A 20 percent cruise might be used for high-value stands, 10 percent for medium value, and 5 percent or less for low-value areas. This arbitrary method is better than using acreage alone, but it may not be the most economical and efficient.

By statistical methods. This requires a preliminary cruise or a good estimate of the variability within each class before the required number of plots per class can be computed. It is suitable for large tracts, but may be costly or unwieldy for small areas.

By a combination of area and value (volume). This is the preferred approach for small areas. Two allocation methods will be

presented, one based on arbitrary weighting of photo variables according to area and value, the other based on area and a rough estimate of volume per class.

Allocation by weighting photo variables.--Assuming that a total of 400 field plots will be measured, the coded photo variables are weighted according to relative importance, giving consideration to both area and value. Here, the three forest types are weighted as follows: P=5, PH=3, and H=2. Density classes, beginning with the lowest, are weighted 2, 5, and 3, and height classes, 1, 2, 3, and 4, in increasing order. To simplify calculations, classes and weights are arranged as in Table 9.

Table 9.--*Allocation of 400 field plots by assigning weights to photo variables* [1]

Total heights		PINE Weight 5 = 200 plots. By crown density classes--			PINE-HARDWOOD Weight 3 = 120 plots. By crown density classes--			HARDWOOD Weight 2 = 80 plots. By crown density classes--		
Class (feet)	Weight	5-35 percent Weight 2= 40 plots	35-65 percent Weight 5= 100 plots	65-100 percent Weight 3= 60 plots	5-35 percent Weight 2= 24 plots	35-65 percent Weight 5= 60 plots	65-100 percent Weight 3= 36 plots	5-35 percent Weight 2= 16 plots	35-65 percent Weight 5= 40 plots	65-100 percent Weight 3= 24 plots
0-20	1	4	10	6	2	6	4	2	4	2
21-40	2	8	20	12	5	12	7	3	8	5
41-60	3	12	30	18	7	18	11	5	12	7
61+	4	16	40	24	10	24	14	6	16	10
Total		40	100	60	24	60	36	16	40	24

[1] Calculations are simplified if weight total for each class is 10 or a multiple thereof, as in this case.

The weight total assigned to each of the three classes is ten. Thus pine stands (weight 5) will receive 5/10 or 200 of the total plots, 3/10 or 120 will be in pine-hardwoods, and 2/10 or 80 in hardwoods. The proportions for each height and density class are similarly computed: within the pine type, 5/10 or 100 of the 200 plots will be in the middle density class of 35-65 percent, and of these 100 plots, 2/10 or 20 plots will be taken in the 21- to 40-foot total height class, and so on. Where proportions result in fractional numbers of plots, these are rounded off to the nearest whole number.

It will be noted that the middle density class (35-65 percent) is given the largest weight of 5 even though the 65-100 percent class presumes greater volume per acre. This weighting better distributes the samples over the largest area, assumed here to be in the middle density class. If the weight of 5 were assigned to the 65-100 percent class, the greatest number of plots (40) would be assigned in the height group for trees 61 feet or taller. Stands with the greatest volume per acre often occupy small areas; thus the density weight of 3 appears more appropriate for compromising the distribution between area and value. Relative weights of the height classes or forest types might also be altered to make allowances for the area factor. By trying several combinations, the forester can arrive at final weights that will control both the minimum and maximum number of plots taken in any category.

Allocation by area and estimated volume.--It is assumed that the tract area is 1,600 acres and that 400 field plots are to be distributed among three forest types (P, PH, and H) and three volume classes within types (5, 8, and 12 cords per acre). The method is adopted from Johnson (4), and Spurr (18).

(1) Stratify each forest type into volume-per-acre classes on the basis of personal experience or with aerial stand-volume tables. Precision is not required as the volume classes are used only as a guide. Tabulate by type and acreage as shown below:

Cords per acre	Acreage by forest types		
	Pine	Pine-hardwood	Hardwood
5	120	200	100
8	100	500	350
12	80	100	50
Totals	300	800	500

(2) Multiply the number of acres in each of the above classes by the cord volume per acre. This yields the number of cords per class:

Pine		Pine-hardwood		Hardwood	
5 x 120 =	600	5 x 200 =	1,000	5 x 100 =	500
8 x 100 =	800	8 x 500 =	4,000	8 x 350 =	2,800
12 x 80 =	960	12 x 100 =	1,200	12 x 50 =	600
Totals	2,360		6,200		3,900

(3) Add the cordage in each class to get the total for the entire area: 2,360 + 6,200 + 3,900 = 12,460 cords. Divide by the number of plots to get the number of cords per plot:

$\frac{12,460}{400}$ = 31.15 cords per plot.

(4) Divide the volume for each class (item 2) by the cord volume per plot to get the number of plots assigned to each class. Round off to the nearest whole number. Add the plots for each class to make sure the total (400) is correct.

Pine	Pine-hardwood	Hardwood
$\frac{600}{31.15}$ = 19.26 (19)	$\frac{1,000}{31.15}$ = 32.10 (32)	$\frac{500}{31.15}$ = 16.05 (16)
$\frac{800}{31.15}$ = 25.68 (26)	$\frac{4,000}{31.15}$ = 128.41 (128)	$\frac{2,800}{31.15}$ = 89.88 (90)
$\frac{960}{31.15}$ = 30.82 (31)	$\frac{1,200}{31.15}$ = 38.52 (39)	$\frac{600}{31.15}$ = 19.26 (19)
Plot totals (76)	(199)	(125)

Total: 400 Plots

If type boundaries have been accurately delineated and stands are homogeneous within the recognized classes, field plots can sometimes be taken along routes of easy travel without introducing much bias (4, 6). Usually, though, it is necessary to lay out line-plot or strip cruises across the area to sample all classes with the desired intensity. These lines should be drawn to scale on the prepared type map in such a way that the required number of samples within each class can be obtained. The number of plots or chains of strip that a crew can complete per day is the basis for calculating the lengths of the lines. To minimize travel, lines should be triangular or U-shaped, beginning and ending near the same starting point on a road or trail. Compass bearings and distances can be determined on the map to avoid location bias in the field. The cruise lines can then be placed on the photographs for use in the field, if desired.

Field measurements are taken by conventional procedures. Cumulative tally sheets or point-sampling may be employed to speed up the tree tally. After the cordage per acre for each volume class has been determined by field sampling, the values are multiplied by the appropriate stand acreages. The result is the total volume on the tract, by forest types. Basic calculations are illustrated below:

PINE TYPE

Assumed volume class (cords per acre)	Field plots	Field volumes	Type area	Volume per class
	Number	*Cords per acre*	*Acres*	*Cords*
5	19	3.9	120	468.0
8	26	8.2	100	820.0
12	31	11.3	80	904.0
Total	76		300	2,192.0
		PINE-HARDWOOD TYPE		
5	32	5.8	200	1,160.0
8	128	7.7	500	3,850.0
12	39	14.1	100	1,410.0
Total	199		800	6,420.0
		HARDWOOD TYPE		
5	16	4.7	100	470.0
8	90	8.6	350	3,010.0
12	19	13.5	50	675.0
Total	125		500	4,155.0

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OTHER SOURCES OF INFORMATION

Photographs may be applied in many projects that have not been covered in this paper, e. g., road planning, topographic mapping, evaluation of forest site, erosion control, watershed management, real estate assessment, plantation survival checks, and forest insect surveys. The two bibliographies listed below will assist the reader in locating specific articles on these and other phases of aerial photo interpretation:

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